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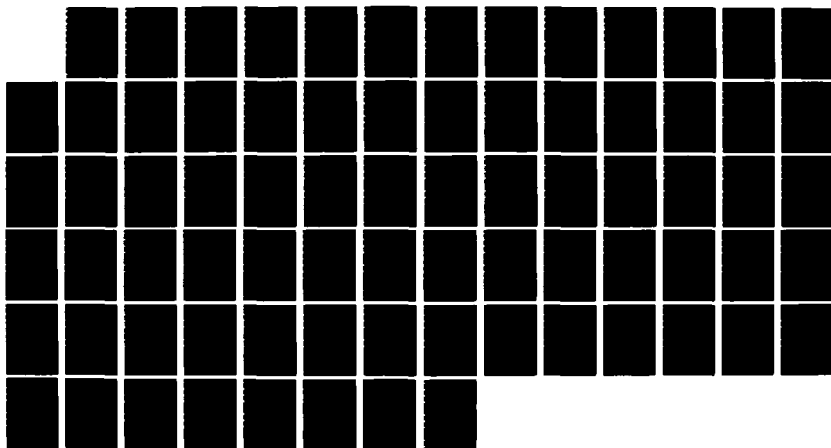
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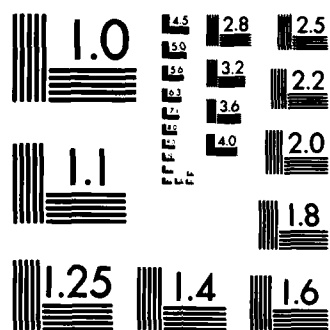
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COMPUTERS IN CHINA

by

James W. Hills, III



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INTRODUCTION

The Chinese, with a documented history of almost 4,000 years, have been trading with the Western world for a considerable part of that time. Silk, for example, was a Chinese secret and monopoly until the silkworm, smuggled into Europe about A.D. 550, was traded for thoroughbred horses, colored glass, myrrh, wool, and linen. Marco Polo's tales of travel and adventure gave the thirteenth-century Western world one of its glimpses of the fabled "Middle Kingdom." His account of the great court of the Mongol Kublai Khan and China's peoples was the first detailed record of China by a European. At that time Chinese achievements in literature, philosophy, art, and craftsmanship were among the highest in the world. Christopher Columbus, perhaps lured by fabulous tales of unparalleled wealth and untold riches, sailed for the Middle Kingdom but found America. Legions of explorers and merchants dreaming of a direct route to the treasures of the Orient followed Columbus.

The United States, too, in her few centuries as a nation, has done considerable trade with China. There are conflicting reports on whether this exchange of goods strengthened or damaged China's own economy; but whatever the actual story, there can be little doubt that the United States, at least as a young country, benefitted from the relationship. As a newly independent nation, the opportunity to trade for Chinese goods, especially tea, made up (at least in part) for being locked out of the valuable sugar trade with the British Caribbean islands.² The export of kerosene to China by Standard Oil is merely one example of later profitable trade arrangements.³

However, in the mid-1900s trade between China and the U.S. was suddenly brought to a standstill. This was a result, not of actions by one nation or the other, but rather of actions by both

nations. The United States Congress passed the export Control Act on February 26, 1949, allowing the executive branch to prohibit the export of any products deemed necessary for U.S. foreign policy or national security.⁴ When the Korean War erupted in June 1950, controls were made even tighter until there was virtually no trade at all.⁵ The corresponding move by China was, of course, her self-imposed isolation.

The combination of U.S. controls and Chinese isolation effectively eliminated trade until the early 1970s. The Nixon administration had begun making efforts, in 1969, toward political rapprochement with China. The final result was President Nixon's trip in February of 1972.⁶ At the same time, China was beginning to rethink her opinion about relations with the U.S. There are several possible reasons for this revision in attitude, ranging from fear of growing Soviet hegemonism, to the benefits to be gained from a relationship with the more technologically advanced U.S. In any event, this newfound friendship resulted in the Shanghai Communique, a resumption of state relations in 1979, followed by the U.S.-China Trade Agreement in 1980.

Both of these documents lauded the benefits to be gained from economic relations,⁷ and it appeared that there should indeed be mutual benefit. The U.S., with her capitalist economy, stood to gain a great deal from the new market alone, not to mention cheaper labor and raw materials. China, however, was shooting for a somewhat different goal--modernization of her economy.

There were basically two reasons for this new effort toward

economic modernization. First of all, China's leaders felt they needed more strength to face what was viewed as a growing Soviet threat. They did not believe that China's present industrial capacity was great enough to meet the demands of both the military and civilian sectors.⁸ In addition, they wanted to raise the low standard of living in China.⁹

So, in March 1978, the Chinese government introduced a new development plan for China: a plan to modernize the economy by the year 2000. Not only was the plan ambitious, but it also contained a major shift in policy. Instead of relying primarily on her own economy to create such growth, the government began allowing--even encouraging--foreign businesses to have a hand in China's modernization.¹⁰ Self-reliance had become an end instead of the means.

In their new policy for modernization, the Chinese leaders put emphasis on four major sectors of the economy: industry, agriculture, defense, and science and technology. The industrial sector was to receive the most attention. However, this did not relegate the other areas to a fate of no growth at all. In fact, China's leaders realized that "it may be possible (although unlikely) to run an agrarian, regulated, controlled, centrally planned society of a billion souls without computers, but a modern society based on industry, information and services is impossible without them. And China's leaders are anxious for their country to become a modern society."¹¹ They also feel that modern technology is a requirement for Chinese security, independence, and influence in today's world.¹² As a result,

they are putting a great deal of emphasis on computer technology as well as industry. One of the hopes in trying to accelerate the growth of the computer science industry is that such growth will also have a positive effect on all other areas in the Four Modernizations. The problem, of course, is that China's computer industry is just as far behind the West as all her other industries.

Although China has taken great strides toward improving the level of her computer industry, the central question remains--can China reach her goal of modernizing her computer industry by the year 2000? Several factors influence the answer to this question: the government has been accused of being too restrictive in allowing foreign business to enter China; centralization of all decisions and policies regarding computers may be slowing progress; a lack of technical information remains even after the period of isolation has ended; and, the government may simply not be placing enough emphasis on computers to make significant gains. Finally, there remains a worry that it may be just too difficult to catch up after falling so far behind in a field which progresses by leaps and bounds.

This paper has been written in the hopes of answering, or at least shedding some light on, the question asked above--will the Chinese modernization effort be successful? Toward this end, four basic sections have been organized. The appendix and the first section are somewhat alike in that they both provide background material. The appendix is an extremely brief introduction to the history of computers as a whole. It should be of some help not only in providing background but in understanding the terminology

of computer science. However, since such a history is not as relevant to a study of computers in China as the other sections, it has been included only as an appendix.

The first section describes the history of computers in China. In conjunction with the history of the appendix, this will be useful in making comparisons between China's computer industry and more developed computer industries and in making judgments concerning the various courses that Chinese computer development might take.

The second section compares the Chinese computer industry and its products to their counterparts elsewhere and analyzes some of the problems that may have a detrimental effect on the growth of China's computer industry. The third discusses a few other instances of technology transfer and provides a comparison of these instances and their success to the case of computer technology transfer.

HISTORY OF COMPUTERS IN CHINA

The early history of computers in China is nearly exactly the same as the history of computing elsewhere. In all likelihood, the Chinese began counting on their fingers just as people everywhere else did. They may have started using pebbles, or lines drawn on the ground with a stick, but eventually, the abacus found its way to China. Here, too, the abacus was extremely useful with its ability to perform normal computations quickly even for fairly large numbers and it became the common tool of calculation throughout China.

It is at this point in the story that the history of computers in China begins to differ. Whereas the abacus began to fall into disfavor in many places by the twelfth and thirteenth centuries because of the general merchant dissatisfaction with its limitations, the abacus enjoyed continuing popularity in China. Use of the abacus had been raised to a fairly high art, with fairly complex calculations possible. As a result, the Chinese lacked the stimulation present in Europe to develop mechanical calculators; they were entirely satisfied with the abacus and it remained the standard computational device. Calculators of some sort may have been introduced by Western countries when they began to expand their commercial activities to include China, but the Chinese had little interest in such tools and the abacus remained the computational tool used in China. In fact, even today the abacus is present throughout China: in most offices, restaurants, hotels, and stores. Even the Friendship Stores use an abacus, and often, even when modern equipment is available and is used, the answer may be checked on the abacus!

While the history of the computer in the West progressed from mechanical calculators, to electro-mechanical devices, finally to computers, all the while with the hope of increased computational power in mind, the path of computers in China followed a much different path. The abacus remained the main tool for calculations, and the field of electricity began to be developed. After all, developing electronics was much more important to improving China's military strength; and such development was deemed necessary during the period of constant

war following the fall of the Ch'ing dynasty (1644-1911).

When the Communists took over China in 1949, they inherited about ten "small wire and wireless telecommunications factories."¹ These facilities became the seed for China's electronics industry--an industry that fostered the growth of computing machines in China. Finally, after ignoring the computational field for so long, the Chinese began to emphasize such research to enhance their world standing. The Institute of Computation Techniques at the Academy of Sciences in Beijing was established in 1956,² and is the first such institute of computer research in China of which mention is made.

China depended upon the USSR for much of her support in computer research until that support was withdrawn in 1960.³ As in the United States, the initial Chinese research centered upon analog machines. By 1958, thirty such machines had been constructed.⁴ However, the Chinese too finally concentrated most of their efforts on digital machines, learning their theory from the Soviets. When Dr. Antonin Svoboda of the Research Institute of Mathematical Machines at the Technical College in Prague, Czechoslovakia returned from a trip to China in the late 1950s for the purpose of lecturing on digital computers, he reported that there were three separate computer groups in Beijing, all using Chinese parts to construct their computers, but Russian designs (the BESM, M-3, and Mark III models).⁵ The first Chinese-built computer was the "August 1" completed in 1958.⁶ But the Chinese still relied heavily on the USSR for guidance.

In the early 1960s, following the Soviet withdrawal, China

began to import electronic equipment from several other countries: France, Japan, the United Kingdom, and West Germany.⁷ For several years, the U.K. was China's largest supplier of such machinery;⁸ but, in 1964, China made the significant technological advance of beginning to use semiconductor components in parts of her computers.⁹ As a result, the amount of these imports decreased somewhat as China gained a measure of self-sufficiency.¹⁰

China's first large, completely transistorised (second generation) computer, the DJS-21, was announced in 1964, and exhibited in Beijing in 1966, from which time all computers produced used this technology.¹¹ By 1971, the Chinese electronics industry was valued at an estimated one billion dollars and was capable of producing not only transistors, but special purpose vacuum tubes, printed circuit boards, and even simple ICs, thus giving the Chinese computer industry the ability to produce third generation computers.¹² Experts felt that at the time this ability to manufacture their own integrated circuits placed the Chinese ahead of the Russians, who still imported their ICs.¹³

It seems that Chinese computers also managed to find a market. Small numbers of machines are believed to have been installed in Albania, North Vietnam, and perhaps Pakistan.¹⁴ Admittedly, exporting computers to these countries was not as great a feat as selling to the likes of Japan or the United States, but it at least gives one the impression that Chinese computers were worth having and probably better than their Soviet counterparts.

In spite of this progress, computers failed to have a strong impact within China. Production of all necessary components was possible, and the components could be assembled into complete computers, but the number of computers in use remained quite small. By the end of 1971, the United States had some 85,000 computer installations. The Soviet Union had an estimated 7,700 such facilities. In comparison, at the same time, the Chinese had only 200 or so locations using computers!¹⁵

Why was interest in developing a modern computer industry so low in China? There are several possible reasons. First of all, the Cultural Revolution was in progress during the later 1960s and earlier 1970s. This movement discouraged people from advocating the unpopular Western sciences. In addition, the Chinese were under the tremendous load of trying to modernize other aspects of her economy--especially industry. Added to these two facts, the abacus, which had been used for centuries, met most of the calculation needs in China; there was simply not much need for a computer. Finally, the lack of sufficient demand for computers from her underdeveloped economy, as well as the lack of the competition that spurred Western developments, stunted the growth of China's computer industry.

Although progress before and during the Cultural Revolution was rather limited, a number of developments have been made since. For example, by 1979, the Chinese had the ability to produce IC computers (their 100 and 200 series) in volume, they had constructed an IC computer capable of five million calculations per second, and production capacity for large and

medium size computers had reached a level of four hundred per year.¹⁶ More recently, by 1984, Chinese researchers had successfully developed floppy disks and character processing systems;¹⁷ and in 1985, the Beijing Review reported that China could mass produce some micro-computers--such as the Great Wall 0520 and the Zijin II--at the rate of about 10,000 annually.¹⁸ But most astonishing of all is a report that Chinese scientists have built China's first supercomputer, the Galaxy, with the capability of performing 100 million operations per second.¹⁹

With such momentous developments under their belts, and considering the fact that Japanese and American computer companies--the most advanced in the world--are lending aid to China, it might seem that the Chinese are on the cutting edge of computer technology. However, there are several problems. Even the Chinese admit to some of the ills facing their computer industry: their scientific research is weak in that it is not ahead of actual production; the technical level of computer equipment does not meet development needs for the rest of their economy; and management is backward.²⁰ To examine the effect of these and the many other problems confronting China's computer industry, let us compare the present levels of the Chinese and American computer efforts and discuss China's recent progress in detail.

COMPARISON AND ANALYSIS

Comparison of Chinese and U.S. Efforts

Vaughn Mantor, who visited the PRC with twenty-six other Americans, found that the Chinese computer industry is

approximately ten to twenty years behind the U.S. with software problems similar to those we encountered when at that level.¹ This means that instead of preparing to move into the new fifth generation as Japanese and American computer manufacturers are doing, the Chinese industry is at best in the middle of its fourth generation with some of its equipment dating back as far as the beginning of the third generation (integrated circuits) in the United States.

As with the problems enumerated earlier, the Chinese recognize this gap. For instance, although Yang Tian-xing, deputy chief engineer of the North China Computer Technology Institute, stated during a presentation on computers in China that the Chinese were producing many fourth generation products, he admitted that there was also a great deal of room for improvement.² Further highlighting the difference between U.S. and Chinese computers, a Chinese author describing the current state of affairs in China's computer industry enumerated several problems: disk drives are hard to find and maintenance services are nearly non-existent; the Chinese lag behind their Western counterparts in consulting, systems analysis, and maintenance; and, China's numerous small, isolated computer enterprises hinder standardization.³ Thus, even though the Chinese have managed to produce a supercomputer like the U.S., most of the computers available to Chinese users are of far lower quality than those to which American users have access.

This fact compels us to make an important distinction-- between computer technology and a computer industry. Computer

technology is simply the technical expertise available in the field of computers. Basically the level of computer technology in a country is determined by the amount of research performed by its scientists, their knowledge and understanding of developments on the leading edge of technology, and the technology included in experimental machines. A computer industry, on the other hand, is merely the application of that computer technology to the regular and fairly large-scale production of computers for public use. Obviously it is entirely possible for the level of a country's computer technology to be fairly high while its computer industry lags far behind in implementing this technology. This is precisely the case in China. While her computer scientists are advanced enough to produce supercomputers, her industry is incapable of incorporating many of the newest features and her population is largely unable to use the computers that are produced.

The blame for this enormous difference between Western and Chinese computer industries can be assigned, as with most other gaps, to isolation and the Cultural Revolution. The effects on China's computer industry were even greater than the negative influence felt in many other areas. Not only did China miss the technology, but due to the suspicion and punishment reserved for intellectuals, she also lost the opportunity to train technicians and computer scientists. And the impact of the loss was magnified by the fact that at the time, the computer field elsewhere was growing with fantastic speed. The U.S. military was becoming less involved in monitoring computer technology while commercial industry became increasingly interested, and it

was during this exact period that the pressures of competition led to a number of significant breakthroughs: very large-scale integration, general-purpose chips, better hardware, and better methods for writing software.

Chinese Approach to Modernization

As stated earlier, the Chinese hope to build a strong computer industry and eventually catch up to the West. What, exactly, are their aims? How do they propose to change their policy in order to meet these goals? Indeed, is it even possible?

Just as the PRC's leaders announced a general economic modernization plan in 1978, so too they proposed a plan for development of China's computer field. On 18 March 1978, at China's National Science Conference, Fang Yi, vice-premier of the PRC State Council, highlighted a policy for expansion between 1978 and 1986. He suggested that China should begin producing large-scale computers and put a wide range of computers into mass production. He also noted that it was imperative for China to make significant strides forward in large-scale IC technology.⁴

In addition to proposals for improvement in computer production, Fang Yi also called for progress in research and personnel. He stated that "in the next three years we should rapidly develop basic research on computer science and related disciplines", and that by 1985 China should finally have a group of fairly advanced specialists in computer science.⁵ The overall goal of all these changes, according to Fang Yi, was to cut China's lag from the fifteen to twenty years of 1978 to ten years by 1985, and to be caught up by the year 2000.⁶

In order to meet such high-placed goals, the Chinese must be willing to make major modifications in their economic system; and, indeed, they have shown just such willingness. In a statement made in 1980, Li Wei, First Secretary of the PRC, noted that "our policy is to rely on our own efforts and to learn from abroad important advanced technology and equipment."⁷ This idea of accepting foreign technology is just one example of the new receptiveness to change.

There are several striking examples of China's new policy of importing technology from abroad. One such aspect is the existence of new "economic zones" on Chinese soil. The idea behind these zones is that they will encourage foreign businesses, including computer firms, to invest in China because of the cheap land and labor, low taxes, and other advantages.⁸ Such an effort is entirely necessary since the timetable for modernization gives so little extra time.

In addition to these special economic zones, China has also begun allowing joint ventures and compensation trade, both of which can be useful in the effort to infuse China with greatly needed technology.⁹ In some joint ventures, the Chinese have even agreed to consider allowing foreign companies to have complete ownership as long as they bring in the latest technology and promise to find an export market instead of trying to sell to the domestic market.¹⁰ But, even though the Chinese leaders are desperate for technology, they can still afford to be choosy--and they are doing just that. For example, when it was disclosed that China wanted to buy mid-size computers for use in Chinese universities, there were several companies willing to supply

their needs. Instead of simply choosing the cheapest computers, or the computers with the best performance, the Chinese leaders insisted that the company that was chosen would also have to help the Chinese build manufacturing plants for the new systems! In addition, they refused to accept the usual clause in the contract making delivery contingent upon the company's receiving a validated U.S. export license. As a result of these extra stipulations, even though IBM had submitted the lowest bid for the sale of the computers, they lost the contract when they refused to help in the plant construction. Honeywell, who had agreed both to assist the Chinese in building the plants and to do without the normal contract clause, was finally given the award.¹¹

This somewhat unusual contract brings up another significant effort by the Chinese leaders in their negotiations with foreign businesses. Although the Chinese are making every effort to obtain technology, they have also realized that the technology is really of no value unless they have the supporting knowledge of how that technology works and how to create it themselves. Thus, "in addition to actual technologies, the Chinese are pressing hard for technical information."¹²

As a result, there is a growing movement in China to obtain students who are knowledgeable in computer science. As pointed out earlier, Fang Yi stated that one of China's goals is to produce a group of Chinese who are fairly advanced in the computer field. Toward this end the Chinese have begun sending students to some of the best computer schools in the world.

Also, they have often insisted, in contracts with foreign businesses, that in order to sell their computers, companies must also supply training to young technicians. The newly trained technicians are then given the job of installing the equipment under the supervision of the selling company's specialists. The terms of the contract are not considered fulfilled until the equipment has been installed by the Chinese technicians and checked by the company's personnel.¹³

This, then, is the Chinese plan to modernize their computer field. They propose to become self-reliant in the production and use of computers by taking a number of innovative measures: production of large-scale computers; mass production of several computers; vastly improved IC technology; rapid development of basic computer science research and a group of computer specialists through foreign study and on-the-job training; special economic zones; and joint ventures. China's leaders are definitely making strong efforts to develop a modern computer industry. However, there are several obstacles that may prevent them from attaining this goal.

Obstacles

One problem facing the Chinese computer effort could be the fact that the U.S. still has export restrictions on many high-technology items. Computers are, of course, included as such. Export limitations have eased somewhat due to improved Sino-American relations. In fact, Commerce Secretary Malcolm Baldrige called technology transfer one of the strongest links in Sino-U.S. relations, and said that the U.S. was passing export applications for most medium-scale mainframe computers without

the lengthy inter-agency review once deemed necessary. But, at the same time, he warned that although policies have relaxed, we would still "not allow our commitment to assist China to modernize its economy through technology transfers to override U.S. national security interests or enforcement of the Export Administration Act."¹⁴ Thus, it appears that the Chinese are willing to buy more advanced machinery than the U.S. wishes to sell, and that United States' unwillingness to sell some products may have a harmful effect on the Chinese effort to modernize her computer industry.

On the other hand, China has several alternative countries from which she might obtain such technology. First of all, Japan, whose industry is on a level equal with, and in some instances ahead of, the United States', would probably be willing to sell technology which would be of use to the Chinese effort. (The level of a country's computer industry can be assessed by several factors. For example, the speed of operations, the capabilities--of both hardware and software, and the maintenance requirements are all important considerations. Most of these factors can be quantified in some manner.) In addition, Hong Kong has ignored U.S. export restrictions for a long while. In fact, American computers, which may have been refused an export license if applied for, have often been sold to firms in Hong Kong, and then shipped by those firms to China!¹⁵ France, too, has been a leading exporter of computers to China; and countries such as Australia, Brazil, Canada, and New Zealand would gladly take the United States' place in computer trade with China.¹⁶

However, U.S. export restrictions are still somewhat of a problem for the Chinese since their preference is for American technology.

There are numerous other concerns, too. For example, one big question is "How are the Chinese going to pay for all the technology they would like to import?" Basically China has two options: they could either increase exports to gain more foreign capital, or they could ask for loans from companies or foreign nations.¹⁷

First, consider the possibility of increasing exports. Presently China is a primarily agricultural nation, but she has a fairly great domestic demand for agricultural products. Thus, it is unlikely that she would be able to export such products and still feed her population.¹⁸ In the case of increasing manufactured goods, there is the problem that many of China's products are of inferior quality and as a result have very little demand.¹⁹ Without demand, there is no way to increase profits. True, China is making efforts to improve the quality and desirability of her manufactured products, and she is starting to develop her oil and mineral reserves, but these efforts have just begun. The earnings produced by such exports in their first few years would be small compared to the capital required to finance China's purchase of technology. In hearings held by the Subcommittee on Science, Research and Technology and the Subcommittee on Investigations and Oversight of Congress' Committee on Science and Technology in 1980, a general agreement was reached that "China would not be able to earn, through exports, sufficient foreign currency to finance the transfer of

technology desired to meet their development goals."²⁰

In the 1950s and 60s China was able to maintain a trade surplus by tightening control on domestic consumption of products. It is conceivable that they could once again institute such a policy in an effort to increase their levels of foreign currency. However, it would be very difficult for them to reverse the policy instituted in the 1970s and 80s of increasing the people's living standard, especially now that the Chinese people have had a sample of what they had been missing.

The second possibility--that of obtaining loans--should also be examined. In 1978, when announcing the new modernization plan, China's government outlined a corresponding change in fiscal policy: China was now willing to take on foreign debts.²¹ Immediately, foreign banks and governments rushed to meet China's needs. By mid-1979, more than \$23 billion in credit had been made available to China by the West.²² But by late 1979, little of this credit had been used, and it became clear that the Chinese were uncomfortable with the idea of assuming such enormous debts.²³ This reluctance was explained by Chen Jie, a deputy minister of foreign trade, at the signing of the U.S.-China Trade Agreement in May 1979: "The borrowing [to finance trade] from our side is based on our ability to pay. We still stick to self-reliance and hard work.... If I cannot pay, I will not borrow."²⁴

Obviously, with an attitude such as this, the Chinese will refuse to accept the great debt that would be necessary to finance a massive infusion of technology. It should be pointed

out that since control in China is centralized and decisions can change suddenly, this particular policy might be reversed overnight. But, so far, no such announcement has been made. Thus, it would appear that neither of the choices seemingly open to China will supply the required capital. Aggravating the problem even further is the fact that much of the money that China does manage to earn must be used to strengthen other sectors of her economy.²⁵ Money, then, is a major problem facing China's computer effort.

Some people suggest that another major obstacle might exist. They argue that China does not have the ability to absorb all the technology necessary to reach their goals.²⁶ Not only are the Chinese short of technicians, technical knowledge, and true understanding of computer science principles, but they are also weak in transportation, power, management skills, manufacturing ability, and planning--all of which have at least some effect on the computer industry.²⁷ These weaknesses are especially troublesome for the Chinese computer field because the West's computer industry, supported by a more developed economy, is growing at such a frenzied pace. Due to this possible inability to absorb computer technology, it may be the case that China's computer industry will remain behind for years beyond the projected goal. It may simply be too far behind to catch up.²⁸

Another major problem could be what some see as over-regulation of the Chinese computer field. Even though China's industry is not very well standardized, there are several organizations which make an effort to provide leadership. For example, there are the Committee for Science and Technology, the

Ministry of Foreign Economic Relations and Trade, the State Economic Commission, and the Administration of the Computer Industry to name just a few. One obvious problem, as with U.S. over-regulation, is that intense competition exists between these separate organizations.²⁹ Also, they often have different and conflicting ideas that they attempt to put into practice to improve the industry. Such conflict restricts the progress of an already struggling computer field. Finally, the ruling organizations may effect a policy harmful to the computer industry. For instance, recently the Committee for Science and Technology ruled that the Chinese would focus their computer efforts on micro-computers as opposed to mini- and large computers.³⁰ Not only does this decision mean that Chinese products in the latter two fields will remain behind similar items in the West, but it may also prove to be a bad choice since it will be especially difficult for the Chinese to catch up in this sector--a sector which is blossoming at a tremendous rate in the West.³¹ Centralized control does have the ability to outperform decentralized decision-making, but judging from result thus far, it might be more beneficial for China's leaders to change their policy and begin allowing individual companies to make decisions. With this approach, the Chinese computer industry would be more diverse, and the people making decisions would be those who were closest to the problems instead of those removed from them.

The several major difficulties already presented would probably be enough to significantly stunt, or halt altogether,

the growth of any industry. However, in addition to these obstacles there are many other problems which could also have a detrimental effect on China's fledgling computer industry. First of all, two obstructions have been recognized as discouraging foreign investments--investments which are a requirement for computer growth. One is the continuing stipulation by China's leaders that production be only for export and not domestic sale. The other is a question of what China's foreign policy and general political atmosphere will be once Deng dies or becomes less of a force.³²

Another problem resulting from governmental action is the unwillingness of profit-oriented foreign companies to make deals with China in light of constantly changing economic policies. For example, only a few years ago, all purchasing decisions were made centrally. Then, without warning, China decentralized, allowing many of the decisions to order computer equipment to be made by the people who might need them. Suddenly there was a tremendous demand for computers which foreign companies rushed to meet. For instance, in order to meet the increased demand, WANG tripled its staffing in China.³³ Then, once again without warning, the Chinese government announced, in March of 1985, that foreign currency would be subject to central control.³⁴ This move, motivated by government alarm over rapidly dropping foreign currency reserves caused in part by provincial and municipal governments buying personal computer systems without any controls, effectively freezes purchases of computer equipment.³⁵ Obviously, foreign computer companies, who depend on a somewhat stable, predictable market are wary of entering this type of

environment.

The lack of competition has presented a barrier to growth in China's computer industry in the past. However, it was hoped that a recent move encouraging Chinese firms to sell their ideas on the market would produce the missing competition. Many of the independent companies who sold their products in this manner were self-supporting, and often highly successful. But it appears that a new problem has arisen. In actions reminiscent of dynastic China, one such firm was nearly driven into bankruptcy when "local tax collectors--taking advantage of unclear tax laws--began to bleed the institute of all its income, arguing that its newer software programs were really only variations of the same basic product and therefore should be taxed with the higher rate for mass-produced commodities rather than the rate for scientific research."³⁶ This is just as great an obstacle to development of a computer industry as the lack of competition.

Education, too, presents quite a challenge for the Chinese. As described in the previous section, new contracts negotiated with foreign computer firms require those firms to train Chinese technicians. And in response to a statement by Deng Xiaoping that computers should be popularized by teaching their use to children, computers have been placed in primary and secondary schools in as many as ten different provinces and municipalities.³⁷ However, evidence indicates that these efforts have not yet eliminated the education problem. Most telling is the fact that today there are an estimated 100,000 micro-computers not being used either because the right peripherals are

not available or because personnel have no training in how to use them.³⁸

This lack of knowledgeable people was apparent while I was in the PRC during the summer of 1985. Although some stores and hotels had modern cash registers and calculators, the clerks usually just ignored them, instead figuring purchases in their head, on paper, or on an abacus. In addition, even though several computer stores displayed personal computers in their windows, I never saw anyone in the stores. This indicates either a lack of education on computers, or a lack of funds to purchase them, or both. In the latter case, the opportunity to educate society by allowing them to experiment with computers on their own--as Americans do--is being lost.

Yet another example of the continuing low education level is given by Thomas R. Wilson, a researcher with the East-West Center's China Energy Project who recently visited the computing centers for many of China's oil refineries. He reports that not only did the Research Institute of Petroleum Processing (RIPP) for SINOPEC (an organization of some 750,000 employees) have just a UNIVAC 1100 and five IBM XT computers, but two of the XTs had no system files on their hard disks.³⁹ In other words, there was no way to use the computers unless one had his own copy of such files on a floppy disk--a poor practice since it wastes the disk space of all users.

Aggravating the shortage of knowledgeable computer personnel is the fact that instead of trained computer scientists being used to modernize the computer industry, or to write software for important Chinese industries or research efforts, some are being

used for seemingly less important tasks. K. C. Liu made the comment while a visiting professor of history at the University of Hawaii that a niece of his in Mainland China had attended one of the best computer schools in China (in Beijing) only to be assigned to a software design group writing computer game programs for export to the United States!⁴⁰ True, the Chinese need foreign currency, but trying to export software to the U.S., one of the most advanced countries as far as software is concerned, is not likely to be of much help in answering this shortage. Their trained computer scientists would be of much more use in advancing China's modernization effort directly.

Problems related more specifically to computer science include the fact that technical information is scarce in China. Such information is still frowned upon by the government, and is expensive (especially for individuals, since China's wage scale is so low).⁴¹ In addition, the technical resources available are often in English. Thus, Chinese interested in computers must either be bi-lingual, or use translators who often know nothing at all about computer science.⁴²

In the same vein, the Chinese language is a problem in word processing. Since the Chinese language is composed of literally tens of thousands of characters, it would be impossible to devise a keyboard like that used for inputting English--a language which has only 26 letters. James Unger, who has studied the problems associated with Japanese word processing (a quite similar situation) says that it is possible to devise a system to handle Chinese characters.⁴³ In fact, the Chinese themselves have

developed several dozen character processing systems,⁴⁴ and in all more than two hundred different approaches have been presented, but none of them is as efficient as systems available for word processing English.⁴⁵

Among the solutions to the problem are boards with only the most widely used 2,000 characters, on which the user simply selects the character desired; systems allowing the user to draw the character; or an approach in which the user types pinyin and the computer finds the appropriate character. However, as with all of the systems thus far designed, each of these approaches has its drawbacks. The first, a board containing all the possible characters, has at least two problems. First of all, only a certain number of characters are listed, thus allowing the possibility that the desired character is not present. Second, even if the board is expanded to include all characters in the language, it remains basically a hunt-and-peck method, and is thus extremely slow. Systems which allow the user to draw the character are nice in that they allow access to all characters, but it is just as slow as writing and often, due to people's different writing styles it does not recognize the character drawn. Finally, a pinyin approach is slow since the Chinese language contains so many homophones.

Added to the shortcomings of the individual systems are a number of problems common to all of them. First of all, as stated before, they are inefficient. According to Unger, an input speed of approximately two hundred characters per minute is necessary in order for character input to be as fast as English. Instead, even trained operators can reach a speed of only fifty

to sixty characters per minute.⁴⁶

A second problem exists because there is no real standard. Thus, there are a multitude of systems making it difficult for operators to work on all machines. WANG has developed a system offering the twelve different approaches it feels will eventually become standard in the hopes that the user will find at least one to be satisfactory.⁴⁷ But even twelve different typing methods would be intolerable to a Western word processor operator. In addition, in talking to the Chinese who have used the various approaches, Thomas Wilson discovered that they do not really like any of them.⁴⁸

Also, the approaches are often physically exhaustive to use and expensive in terms of storage (each character requires two bytes).⁴⁹ Finally, manipulations such as sorts and comparisons are meaningless since characters have no order as an alphabet does.⁵⁰ Yes, dictionaries do place characters in some order; but it is totally arbitrary, and the method of classification has been changed several times.⁵¹ Some solution to all these problems may eventually be discovered, but for the time being word processing--a major use of computers in the West--remains fairly difficult for the Chinese language.

Another problem related to language is that in addition to research materials often being in foreign languages, the software used on Chinese computers is usually written in English or some other language.⁵² True, the prompts for the user to input data are sometimes in Chinese, but the program itself is written in a foreign language. Thus, if some bug in the program eventually

turns up, the Chinese using the program must have a knowledge of that language. This means that not only computer researchers, but even everyday users must be competent in foreign languages. How would it be if every person in the U.S. who wanted to use a computer had to be knowledgeable in a language besides English--say Chinese? This is the situation in China unless a new industry suddenly springs up offering multi-lingual programmers to correct any program that has bugs in it.

One might suggest that this problem could be alleviated by simply allowing the Chinese to develop programs in their own language. However, this is not nearly as easy as it sounds. First of all, if one wishes to allow the direct input of instructions in Chinese, he immediately faces all the problems described in the discussion of word processing Chinese characters. Since programming normally involves only a set number of commands, and thus little or no ambiguity, this situation could be eliminated by some solution such as the use of function keys for programming. However, this too presents some difficulty: all programs already written in a foreign language must be rewritten--no easy task!

The Chinese have been faced with producing some of their own software because the software from foreign companies is simply inapplicable to Chinese needs.⁵³ Until quite recently, obtaining domestic software specifically designed to meet the needs of a Chinese firm was extremely difficult.⁵⁴ Moreover, efforts to meet such demands exacerbated other problems: the lack of trained software engineers and the lack of standardization in creating software. However, as a result of the reform mentioned

earlier--allowing firms to offer their products commercially--it appeared that the software shortage had been met.

The additional measure of establishing "a national software company...to facilitate information exchanges and streamline the production of the various software departments"⁵⁵ should have also exerted positive influence on the lack of standardization. It seemed that Chinese software had finally begun a bright era. Western sources echoed the Chinese optimism,⁵⁶ but at the present time, the evidence shows that the quality of Chinese software remains at a low level.

For instance, according to Thomas Wilson, until his organization supplied refineries with a modern linear programming (a technique for maximizing functions such as profit with respect to several constraints) software package, many of them, such as the Qilu refinery in Shandong province had no models at all--someone simply guessed at values for profit, production, and so on, or else took months to calculate such numbers by hand. The technique of hand calculation went out of vogue in the U.S. in the 1950s with the advent of linear programming. Calculations that were performed at Qilu by hand took months, while simulations on computers using the linear programming software package supplied took only five minutes. Wilson, noted that China's State Science and Technology Commission had been researching linear programming, but the approach they used--huge lists describing the row and column coordinates of values, and the number itself--was similar to that used in the U.S. in the late 50s and early 60s. The U.S. has now improved their method

by using tables with meaningful labels instead of these long, error-prone lists. Wilson felt that in regard to software, the Chinese were at least fifteen to twenty years behind the U.S.⁵⁷

Briefly, there are yet more problems. Input and output methods are not only unsuitable for Chinese characters, but are also often antiquated.⁵⁸ These old I/O methods are much slower than newer techniques, which means that valuable computers are tied up unnecessarily. Computers are expensive due to the high costs of parts, their low availability, low reliability, and bad service. (A Chinese micro-computer can cost \$14,000, while in the United States a good-quality machine can be bought for under \$2,000.) Low labor costs aggravate this problem because they make expensive computer use unattractive.⁵⁹

Obviously the Chinese computer industry is faced, not with one obstacle, or even two, but instead is plagued by a multitude of them. In addition, these problems are not minor nuisances that will simply disappear someday. They must be faced squarely with the best comprehensive plan to reach realistic goals. Has the Chinese leadership come up with the most effective course of action to modernize China's computer industry? To provide an answer, three possible policies for directing a computer sector are presented below and compared to the present Chinese policy.

Possible Approaches to Modernization

The first alternative for a country wishing to gain the benefits of using computers is simply to use computers effectively. The advantage of this approach is that it does not entail the costs of building a huge domestic computer industry,

but does provide many of the positive aspects of computers.

At the same time, though, there are several disadvantages to such a proposal. First of all, if a country merely buys everything--hardware, software, personnel--it is totally at the mercy of its suppliers. If hardware begins to malfunction or software has bugs, there is nothing to do but wait for the supplying company to supply service. Anyone who has had to deal with a store for repair of faulty equipment, or with a garage when a car breaks down, is familiar with the bad feelings involved in having to trust others to do work reliably and in a timely manner. Additionally, the expense that was avoided by not having to build up an indigenous computer industry is not truly money saved. On the contrary, a new, probably greater, cost is now incurred--that of purchasing everything. Also to be realized is the fact that while it is possible to purchase much of what is necessary for using computers, the time, money, and effort must still be expended to train people in the use of those machines and their programs.

Such an approach to using computers is obviously ludicrous. It seems much more sensible for a country to purchase only part of its computer technology--say the hardware--and develop its own capability to meet needs in the other areas. However, in reality, even with this modification the costs and dangers of the first possible computer policy are still present.

Furthermore, allowing the firms of other countries to dictate the hardware and software available is not only frustrating if what is available does not meet requirements, but

can be dangerous in a world where international relations are constantly changing. For China, a country that many nations already have export restrictions against, such a policy is foolhardy: they would probably never have a modern computer sector, but would instead be relegated to equipment and programs already somewhat outdated. Although China may at present seem to follow this course in that they are dependent in some areas on foreign firms importing computer technology, they are not truly using this approach since they continually express their desire to become self-reliant.

A second possible policy for gaining computer power might be to develop an indigenous computer industry with the ability to meet national needs, while the third option is to build an industry capable of competing at the forefront of the international computer technology race. The benefits of these two possibilities are essentially the same: the ability to solve national problems that require the use of computers, and self-reliance, thus eliminating the fear of trade sanctions and the like. The costs--for education, training, research, and the initial technology--are also similar. The only real difference is that with an industry advanced enough to market its products internationally, the benefit of increased foreign capital is added.

Of these last two policies, which are the Chinese following? Since they would probably like to have the extra foreign exchange, one might assume that they would follow the latter course. I believe that the Chinese are indeed using this approach, but not especially for the extra capital to be gained.

Instead, for China, there is simply little difference between the two possibilities. She is a country with the size and population to be equal with the United States and the Soviet Union. Since she has stated this desire, and has initiated among other things a space program and great economic reforms, a computer industry with the most advanced technology available is a necessity.

The idea has been advanced that although China's computer industry has currently not reached this level and faces many obstacles, it might be able to jump into the technological lead simply by making, or taking advantage of, some innovation. While this possibility does exist, it is extremely remote. In order to make such an idea worthwhile, the Chinese would first have to eliminate many of the obstacles mentioned earlier that presently face their computer industry. This in itself will require time and a tremendous amount of effort and is only a prelude to taking advantage of new technology.

Some people may suggest that computers do not need to be distributed throughout China's underdeveloped economy, but may instead be used only by a computer elite responsible for all computing throughout the country. This, of course, is true. Just as it is unnecessary for everyone in the U.S. to have access to a computer, so too it is unnecessary for the Chinese. On the other hand, since the Chinese leaders hope to modernize much of China--her agriculture, science and technology, defense, and industry--every sector of her economy that is to be modernized almost surely requires some use of computers. Although some of the work on these computers may be done by the

computer elite, the remainder must be delegated to those who are closer to the problem. Thus, just as there is a computer elite as well as a group of ordinary computer users in the United States, if China is to reach all of her modernization goals, she must also develop these two groups; and she must do so while at the same time creating a computer industry at least close to the leading edge of technology.

POLICIES FOR INTRODUCING OTHER TECHNOLOGIES

Much of what has been presented so far has depicted China's ability to reach her self-proclaimed goals in the computer field in a negative light. While this viewpoint seems justified given the present state of computers in China and the success of the policy being followed, the possibility exists that China's computer effort is atypical of the programs being followed to modernize other sectors of her society. If such is the case, there may still be hope that by changing to one of these other approaches the Chinese will be able to attain their aim.

This section compares the policies being followed in two other areas of China's economy to that of the computer industry. The first sector--energy production, with particular attention given to the oil industry--is quite similar to computer science in that it is an industry important to China's overall modernization. The second, while also important, is not necessary for modernization, but instead for China's continued existence: her military forces. If the policies followed in both of these areas are similar to that in the computer industry, and they are not enjoying any more success, we shall infer that

our conclusion for the fate of computers in China is justified.

The Oil Industry

China's oil industry is already fairly large. By 1985 there were more than nine hundred different rigs and 280 seismic crews working in the field.¹ In addition, according to David Fridley, a researcher with the East-West Center's China Energy Project, China ranks sixth in the world for crude oil produced and according to estimates may pass Britain to become fifth.² China's oil reserves, at least on-shore, are huge. Her two largest fields are Daqing and Shengli, respectively.³ The former is responsible for 50 percent of total output, but also suffers from a high percentage--sixty percent--of water in its oil; the latter has problems with sand.⁴

The United States' Office of Technology Assessment (OTA) reports that by 1979, production had reached more than two million barrels per day (bpd)--everything appeared rosy. Then, beginning in 1980, production leveled off.⁵ The main reason given for this sudden plateau was that China's major oil fields began to mature, and maintaining a constant rate of oil recovery increasingly required expensive water injection. Adding to the maturity problem was the fact that those governing the oil industry placed too much confidence in the capacity of existing fields and thus ignored exploration.⁶

As a result of this plateau, it appears unlikely that the Chinese will be able to meet their goal of doubling the current production rate of 2.3 million bpd by 2000.⁷ Even now, when the situation has become clear, the Chinese spend only two to three

billion dollars on exploration and development, an amount equivalent to that which would be spent by an average-size U.S. company hoping for only a small part of China's production.⁸ Such a policy is quite peculiar since the Chinese themselves consider energy production to be the weakest link in their development effort (a belief borne out by the fact that due to energy shortages one in every five machines is idle).⁹ Since China has vast reserves of untapped energy sources, some of her shortage could be eliminated by simply increasing her present production capacity. But, such efforts in the oil industry have been "hamstrung by things such as obsolete equipment and lack of technology and money."¹⁰ (These problems sound remarkably like those faced in the computer industry!)

Briefly, most of China's oil rigs are copies of Russian designs.¹¹ According to Fridley, this means that they use technology available to Russia in the 1950s which is roughly equivalent to that of the United States in the 1940s. Fridley notes several other examples of Chinese oil technology: while the U.S. has been using digital seismographs for some time, the Chinese have been using analog machines until recently; they didn't produce their first off-shore rig until the 1970s (the U.S. first produced one soon after World War II) and they still lack the ability to produce rigs for water deeper than fifty meters; and finally, they still have not been able to make deep-drilling bits.¹²

Realizing that the problems were formidable, the Chinese finally dropped their policy of self-reliance and sought to purchase foreign equipment. Not until 1980 did the Chinese

realize that such machinery was not as important as technology and begin to seek foreign training, technical services, and management practices.¹³ Joint ventures were initially limited to off-shore areas. But in April of 1984, when China announced that it would ally with foreign firms to discover and produce oil in ten southern provinces, the response was overwhelming: by October of 1985, fifty-two companies from thirteen countries had discussed the matter with China, and twenty-one groups were already in the process of exploring.¹⁴

How successful have these efforts been? From 1984 to 1985 China's crude oil production had moved from its plateau rising 8.9 percent;¹⁵ the Chinese have successfully sold oil tankers to Norway and have received world certification in tankers and shallow-water drilling platforms from the American Petroleum Institute;¹⁶ and the amount of drilling has progressed from 2.1 million meters in 1984, to 3 million in 1985, to a projected 3.6 million for 1986.¹⁷

However, as with computers, such facts do not tell the entire story. A number of problems still exist. First of all, even though China's production of oil is increasing, the World Bank and the CIA estimate that due to a rapidly rising domestic demand for oil the Chinese will cease to export oil by 1990.¹⁸ Since China's oil industry has been charged with providing foreign capital for much of the modernization effort, news like this dims hope for continuing import of foreign technology. The dilemma is compounded when one remembers that the worldwide price of oil is decreasing. If such conditions continue, foreign firms

will likely be less anxious to enter into new contracts with China, thus decreasing the flow of oil technology into China. Also discouraging for foreign companies is the fact that offshore drilling results have thus far been poor.¹⁹

The shortage of technical manpower is also a serious problem for the oil industry as is the poor decisionmaking inherent in China's bureaucracy.²⁰ But even if the industry were completely modern and producing up to capacity, the Chinese still face a major problem. In contrast to the United States, the Chinese have no pipeline network to transport oil across the country. A few isolated pipelines do exist, but most of the transportation is done by railroad tank cars with a resultant loss of oil of up to ten percent due to the length of time in shipping.²¹ To construct a pipeline from the new oil fields in the northwest--a sorely needed line--the Chinese would have to spend approximately thirty billion dollars, thus straining their already tight budget even further.²²

China is slowly modernizing her oil industry, basically following a policy of using modern technology for new fields while leaving old fields alone, and by the end of the century about half of her industry should be up to standards.²³ But, with so many problems to face in other parts of her economy, and an increasing domestic demand, China can little afford such a low level of modernization. As with computers, because of a number of problems, China's oil industry modernization policy is turning out to be unsuccessful.

The Military

During the Korean War, facing United States troops, the

Chinese soon realized that both their weapons and human-wave tactics were obsolete. As in the cases of computers and oil technology, vast amounts of Soviet military equipment were imported to remedy the situation.¹ This policy was followed throughout the 1950s for all three of China's military branches. After the break with the Soviets, the Cultural Revolution isolated China from the new technology and ideas elsewhere in the world.² During this period, the Chinese tried to be self-reliant. They made very few of their own designs, however, basically just remodeling Soviet equipment that had been imported in the 1950s.

As a result, by the end of the 1970s, although the People's Liberation Army (PLA) was huge, with more troops than even the Soviet Union, its weapons were once again antiquated: many were still 1950 designs.³ The PLA's air force of more than five thousand aircraft was the third largest in the world; but eighty percent of its planes were obsolete MiG-17s and MiG-19s.⁴ In fact, except for the MiG-21, none of China's airplanes was initially built later than the 1950s.⁵ The navy was also large (more than one thousand combat ships), once again third in the world; but, it was a coastal defense force effective only against unsophisticated surface opponents.⁶ Finally realizing that a strong defensive ability is essential, the Chinese leaders have launched, as part of their Four Modernizations, an effort to modernize their forces. Once again they are relying on the import of foreign technology.

This effort has been somewhat successful. A parade in 1984

unveiled at least ten new pieces of Chinese-manufactured military equipment. One Western military analyst characterizing the display as "very impressive," noted that it demonstrated a high level of manufacturing standards. However, in spite of positive signs, a Western diplomat in Beijing maintained that it will take a good while longer to reach the level of the Soviet Union and United States armies.⁸

Since the Soviets are just to the north, the Chinese must equal their level of military preparedness. But, the problems to be overcome may be insurmountable--especially by the end of this century. First of all, defense is the last priority of the Four Modernizations.⁹ With the possibility of reaching goals in the other three areas in doubt, the military situation seems even less hopeful. Also related to the lack of success in other sectors is the fact that military improvement depends on the strength of other areas. To use the examples we have discussed, without a modern computer industry and a strong oil industry, the military effort is doomed.

Several other problems must also be faced. The West is unwilling to export a substantial quantity and quality of military technology; the Chinese themselves are reluctant to sign contracts; in addition to high-technology items, the Chinese must devote time and resources to developing ordinary military hardware; and there is a serious shortage of trained personnel and training for the use of modern equipment can take a long time.¹⁰ Finally, the PLA still has many old soldiers who are unwilling to move over for younger, better-trained soldiers.

The history of China's military is extremely similar to that

of computers and the oil industry: early Russian importation, a period of self-reliance, an eventual recognition of the need for modern technology and techniques, and a request of foreign nations to aid in modernization. But the problems are similar, too. The forecast for the Chinese military effort does not brighten hopes for their computer industry's future.

CONCLUSION

China has given herself the goal of improving her computer industry to a level equal with the West by the year 2000. True, there have been some minor variations in the method proposed to reach this goal. (For instance, in 1980, estimates suggested that the Chinese would probably never import more than \$100 million worth of computers in any given year because such imports would hinder efforts to create their own industry.¹ Then, later, Chinese officials disclosed that they hoped to import \$1 billion of computers and electronic equipment.²) But the main goal of modernization by 2000 has not changed.

Will China be successful in her quest? Even though Chinese foreign policy now seeks the aid of Western nations and allows foreign businesses a place in the Chinese economy, the problems to be faced are immense: lack of capital, inability to absorb the technology, over-control of the industry, and numerous others. The difficulty in reaching the goal is increased because the Chinese are trying to modernize so much of their economy. True, chances would be improved if the Chinese were to concentrate their resources entirely on the computer industry.

Such a development is entirely possible in a centralized bureaucracy like the Chinese have. However, China's leaders have not yet announced a policy of this nature; and in my view it is extremely unlikely that they will do so.

Perhaps the most telling criticism of all is the fact that China appears to be already falling behind schedule. When a group from the U.S. Institute of Electrical and Electronic Engineers (IEEE) visited China in the fall of 1979, they discovered that the Chinese were at least ten years behind the West in computer development.³ However, as mentioned earlier, when Vaughn Mantor visited in August 1983, he found the lag to be ten to twenty years. In spite of the desire stated by Fang Yi to be within ten years of the technological front by 1985, instead of catching up, the Chinese seem to have fallen behind! With so many problems to be faced, and the knowledge that the Chinese plan has been ineffective thus far, there can be little hope that China's computer industry will catch up by the year 2000.

Appendix

HISTORY OF COMPUTERS

One might assume that a computer is simply a large calculator. Actually, a computer "is a machine which is both programmable and universal. A calculator is a machine which lacks either or both of these characteristics."¹ Thus, a computer is not just a big calculator. In fact, it is extremely possible for a calculator to be larger than a computer!

The ideas of programmability and universality may evoke some confusion, but in actuality, the ideas are fairly easy to understand. A machine is programmable if it is able to execute automatically all steps in a set of instructions once those instructions have been stored within the machine; it is universal only if it can produce any number that is capable of being produced by any other machine.² Of course, our idea of universality demands that a machine have an infinite amount of memory (since numbers may be infinitely long). So, it is practical only to apply this requirement within each individual machine's memory restrictions. We might also stress that programmability in this text requires that the machine have the ability to retain its program internally.

Having defined the term "computer," we may now follow its history. With the knowledge that the first true modern computer was not invented until 1948³, one might assume that such a

history would be quite short. But the foundation for the development of the modern computer was laid thousands of years ago!

The history of computers actually begins with man's ability to count. At first, man probably used his fingers to count; but as the number of things he wished to count grew larger, he was forced to use objects such as stones in addition to his fingers to indicate the total number.⁴ This was the beginning of man's use of devices to help him count and calculate and led directly to the invention of the abacus 5,000 years ago, probably in Babylonia (now Iraq).⁵

Although counting and reckoning developed at this relatively early date, it was not until much later--2,000 B.C.--that written symbols were developed to record numbers.⁶ Several early civilizations developed written number systems; but these systems had several drawbacks. Not only were the symbols complex and difficult to write, but there was no zero, and the idea of using place to denote units, tens, hundreds, etc. had not yet been developed.⁷ As a result, the number systems were nearly impossible to use for calculation. (For example, consider the Roman numeral system: the symbols are not difficult to write--until the numbers get large; there is indeed no zero; and anyone who has used the system will acknowledge that having no place notation makes computation nigh on impossible.) However, this posed very little problem since all complex computations could be performed on the abacus. The written system was used only for recording the final result.⁸

Most people today think of the abacus as a foreign object used only in far distant, or backward, countries. However, at one time the abacus was used widely--even throughout Europe. It was tremendously popular due to the fact that no number system was necessary in order to use it: even illiterate merchants and traders could perform calculations.⁹

By the twelfth and thirteenth centuries, merchant dissatisfaction with the abilities of the abacus was creating a demand for increased computational power.¹⁰ The answer to the problem was the Hindu-Arabic numeral system. After the introduction of this system with the Moorish invasions of the eighth and ninth centuries, the abacus was no longer necessary. For the first time, a number system had been developed whose symbols were easy to write and which used the notions of zero and place notation; complex calculations could now be performed with only pen and paper. The transition to Hindu-Arabic numbers was slow, meeting a great deal of resistance, but the change in Europe was generally complete by the end of the 16th century.¹¹

Following the introduction of Hindu-Arabic numbers, mathematicians began inventing various methods and devices for simplifying the often tedious task of computation. In 1614, John Napier, of Scotland, published a paper describing logarithms, and their ability to simplify multiplication and division, for the first time.¹² Soon after this invention, Henry Briggs, an English mathematician, increased the public use of logs by calculating and publishing logarithmic tables.¹³

The trend to simplify calculation continued as William Gunter, another English mathematician, transformed logarithmic

tables into a pictographic form--the "Gunter", which came to be widely used in navigation--in 1620, leading to the invention by William Oughtred, in 1622, of the slide rule.¹⁴ With its ability to greatly speed the process of computation, the slide rule found a warm welcome and was modified for a great many specialized applications. It was widely used for centuries, being replaced only in the mid-1900s when developments finally led to reliable, fast calculators.

Even with the invention of the slide rule, both the need and desire for yet faster and more reliable computational devices grew. Blaise Pascal is often credited with making the next great step in computation with his invention of the mechanical calculator; but the honor actually belongs to one Wilhelm Schickard who invented the first such machine--one that could add and subtract mechanically but multiply and divide only semi-automatically--in 1623.¹⁵ However, even though Schickard may have invented the first mechanical calculator (he called it the Calculating Clock), his invention had very little impact: the enormous potential of the machine was swallowed up by the Thirty Years' War and Schickard himself died of bubonic plague in October 1635.¹⁶

Finally, in 1643, Pascal invented his machine, which was also capable of performing only addition and subtraction mechanically, and even those operations were sometimes prone to error.¹⁷ Pascal's machine, although not superior to Schickard's Calculating Clock, had a great deal more impact; and it is precisely for this reason that his calculator attained fame as

the first mechanical calculator. Invented to help ease his father's calculating burden as tax commissioner, the Pascaline was displayed quite often and demonstrated publicly for the first time that a machine could perform arithmetic operations.¹⁸

A further step was made in the progress of calculators when Gottfried Wilhelm Leibniz, one of the inventors of differential calculus, produced his own machine in 1673.¹⁹ Although Leibniz's machine, the Stepped Reckoner, never worked to perfection, it was able to mechanically carry out all four arithmetic operations for the first time; and more importantly, the principles of operation used by Leibniz (most notably a special gear known as the Leibniz wheel) were the same used in a host of mechanical calculators that would follow.²⁰

One common factor unites the three machines described above: none of them were ever a commercial success. Granted, efforts had been made to market the Pascaline; but they were largely unsuccessful. Not until 1820 was a machine invented that sold well.²¹ Thomas de Colmar's Arithmometer, a commercially manufactured calculator capable of performing all four operations, met with great success, selling over 1,500 units in a period of 60 years.²²

At about this time, the Industrial Revolution was picking up steam. With the Industrial Revolution came rapid growth. The Arithmometer and its contemporaries met with a rising demand for increased reckoning power. Tables, too, popularized by Briggs' logarithmic tables, were more widely used than ever before. Unfortunately, with the rise in the manufacture and use of tables came a multitude of errors: miscalculations,

typographical errors, and even mistakes made on purpose to catch plagiarizers. Needless to say, such errors could cause tremendous problems in such fields as navigation.²³

It was left to the genius of Charles Babbage, an Englishman, to try to solve the problem--and try he did. In fact, Babbage eventually conceived of a machine in the 19th century that failed in only one aspect to be a true computer: it could not store programs internally, but instead had to rely on instructions being inserted.²⁴ His idea was so advanced that not until the 1940s would such a machine actually be built. But Babbage's first machine was not quite so ambitious. He envisioned a machine capable of automatically calculating tables by the "Method of Differences:" thus the name Difference Engine.²⁵

The Difference Engine was not a computer in that it was designed only for using the Method of Differences and thus failed the test of universality. However, it was capable of calculating nearly all tables and would eliminate even the possibility of error when printing the figures by stamping its results on metal printing plates.²⁶ Babbage completed a working model of his dream in 1822, proving that the concept would work.²⁷ But most important of all, the Difference Engine was the impetus for an even greater idea--the Analytical Engine.

The Analytical Engine had been inspired by Babbage's knowledge of two prior inventions known as the Jacquemart and the Jacquard Loom. Jacquemarts had been used in Europe as early as the fourteenth century to control the complex ringing of clock bells. Although the pattern of ringing was always constant,

Babbage decided he could modify the process to allow flexibility, and thus allow the Analytical Engine, unlike the Difference Engine, to follow any set of instructions.²⁸ The Jacquard Loom, invented in 1805 by Joseph M. Jacquard, was controlled by punched cards. These cards, the forerunner of modern-day punch cards, would allow Babbage to feed instructions to his machine.²⁹

Unfortunately, the Analytical Engine was never built: Babbage demanded perfection and constantly revised plans for the machine, thus nullifying progress that had been made; the cost of the project was too much for Babbage to handle on his own and the British government refused to support the project after it had supported the Difference Engine for nineteen years and had only a working model to show for its expenses;³⁰ and the technology of the time was inadequate to construct a machine of such complexity.³¹

The Analytical Engine had several similarities to modern computers--as already mentioned, it used punch cards, and Babbage had endowed it (at least in plans) with a "store" and a "mill," now known as memory and the central processing unit respectively.³² Had anyone latched onto the idea after Babbage was forced to abandon it, the world might have entered the computer age much earlier than it actually did. But instead, inventors pursued the much less complicated Difference Engine. For example, in 1853, Pehr Georg Scheutz and his son Edvard, of Sweden, completed their Tabulating Machine, which although sometimes prone to error, "was the first concrete demonstration of the enormous mathematical potential of machines."³³

From the creation of the Tabulating Machine until after

World War I there was very little real movement toward a modern computer. True, various mechanical calculators were built, improved on, and had commercial success,³⁴ but these machines were merely the fruit of the seeds sown long before by Schickard, Pascal, and Leibniz, and had been preceded in the commercial market by de Colmar's Arithmometer. However, a number of developments during this period that were not directly related to calculators would eventually have great impact on the appearance of computers.

The first contributing factor was a direct result of the United States Census conducted in 1880. Because of the enormous quantity of data collected and the amount of tabulation and analysis required, it seemed that the results of the Census would not be published until just before the 1890 Census.³⁵ Happily, in 1884, Herman Hollerith patented an electromechanical system capable of tabulating census data that had been punched into cards--the world's first data processor.³⁶ Hollerith's invention was important to computer development not because it was successful in speeding the Census, but moreso because it helped to develop cards as an input-output medium.³⁷ Also important is the fact that the company Hollerith founded upon leaving government service was one of three that merged and eventually became the computer industry giant IBM.³⁸

A second factor that aided in the development of the modern computer was the increasing knowledge about electricity. Such knowledge helped in the development of electric relays and vacuum tubes--devices critical in the move towards computers--as well as

by encouraging the use of electricity in calculating machines.³⁹

Finally, scientists and engineers had been increasingly confronted by difficult differential equations. Such equations are extremely important, but equally difficult to solve. It was this problem that led to the next development in the history of computers.⁴⁰

With the aim of making differential equations easier to solve, a group of scientists at MIT under the direction of Vannevar Bush developed a machine in 1930 that was able to either differentiate or integrate equations and show its results graphically--the differential analyzer.⁴¹ Such a machine was an obvious improvement over the methods existing at the time for solving differential equations. However, since its results were recorded graphically, it was not precise (a characteristic of analog machines--for example a slide rule--which can only give approximations of numbers on graphs or scales, as opposed to digital machines such as calculators which give exact numbers to whatever extent their display or capacity allows).

Partly as a result of the progress made with the differential analyzer, and partly in an effort to improve the state of the art several men in the mid-1930s began to experiment with the possibility of creating advanced digital machines. Between 1938 and 1950, in war-torn Germany, Konrad Zuse built four different calculators, ranging from the Z1, an entirely mechanical machine completed in 1938, to the Z3, which used electrical relays and was the world's first working general-purpose program-controlled calculator, to the Z4, which was even more powerful.⁴² But since Zuse was working in Germany his

progress never had an impact elsewhere.

In the United States, Howard Aiken had conceived of connecting a multitude of tabulating machines to construct his own program-controlled calculator. His final product, dubbed the Mark I, was completed in 1944.⁴³ Also in the United States, in 1946, after building four previous machines, George Stibitz, a mathematician working for Bell Labs, constructed the Model 5⁴⁴--a machine much like Zuse's Z4.⁴⁵ Although all three of these machines were fairly large advances in the history of computers, their time in the limelight was extremely short. Almost immediately a far more powerful machine was constructed: the Electronic Numerator, Integrator, Analyzer, and Computer (ENIAC).

In 1943, the United States was deeply involved in World War II. With the production of several new long-distance guns, a crisis began to arise. Each gun required separate firing tables telling the soldiers using it how to aim in order to hit the desired target. Between 2,000 and 4,000 trajectories had to be calculated for each set of firing tables with each trajectory taking a skilled human computer with a desk calculator about twelve hours to calculate.⁴⁶ The Ballistics Research Laboratory, the office responsible for completing these firing tables, contracted to use the differential analyzer at the Moore School of Electrical Engineering at the University of Pennsylvania in an effort to speed the work of its 200 human computers, but even then, by 1943 it was hopelessly swamped.⁴⁷

Herman Goldstine, a lieutenant in charge of work being done at the Moore School for the BRL, was quite aware of the problems

facing his laboratory. As a result, when he heard the proposal of John W. Mauchly--an electronic calculator improving on a smaller machine Mauchly had seen that had been constructed by John V. Atanasoff of Iowa State College--he was eager to investigate the possibilities of such a project.⁴⁸ After meeting with other experts to check the plausibility of Mauchly's idea, Goldstine was able to convince his superiors to sponsor the project in hopes that it would eliminate the firing table crisis. Work began under the guidance of Mauchly and his assistant J. Presper Eckert, Jr. on May 31, 1943.⁴⁹

Many men who had knowledge of the plan to build ENIAC were convinced that it was doomed to failure, if only for one reason--the number of vacuum tubes that Mauchly and Eckert proposed to use. In contrast to even the most extraordinary devices of the time which might use several hundred tubes, ENIAC was supposed to use 18,000 tubes!⁵⁰ Critics were afraid that the tubes would burn out so often that ENIAC would be under repairs more than it was working. But by using common sense and operating the tubes at levels far below the established standards, Eckert and Mauchly managed to greatly reduce the problem of tube failure.⁵¹

When ENIAC was finally completed (it was inaugurated on February 15, 1946), it was an awesome machine: it weighed in at about thirty tons, covered approximately 1,500 square feet of floor space, required 160 kilowatts, and could operate at a speed of 0.2 milliseconds per addition and 2.8 milliseconds for a multiplication.⁵² With such speed it was hundreds of times faster than any machine produced up to that time.

On the other hand, like all the calculators that preceded

it, ENIAC was not a computer. First of all, it could not store a program. In addition, its reprogramming was performed by rearranging its wires into the appropriate configuration for the next problem.⁵³ This feature meant that ENIAC not only failed the test of universality, but that it was extremely difficult to program. In fact, it might even be considered less of a computer than its predecessors. But with its unrivaled computational power and speed, and the fact that it was so difficult to program, it greatly encouraged development of a true modern stored-program universal computer.

Indeed, while working on ENIAC, Eckert and Mauchly themselves had dreamed of improving their creation into just such a machine; and in October 1944, the Army agreed to finance their proposed Electronic Discrete Variable Computer (EDVAC).⁵⁴ EDVAC may well have been the first stored-program computer begun. However, it was not the first completed. In 1946, after ENIAC had been built, the Army Ordnance Department and the Office of Naval Research held a summer course on computers in the hopes of spurring computer development. Great Britain was invited, and the information gleaned from the course, combined with the knowledge they already had, was enough to allow scientists in Great Britain to build the world's first stored-program computer.⁵⁵ Using a memory constructed from cathode ray tubes (CRTs) to store its programs, the British machine--a working prototype known as the Manchester Mark I--ran its first program on June 21, 1948.⁵⁶

Although most of the events preceding the construction of

this first computer took place in countries other than the United States, subsequent developments have, until extremely recently, been almost the exclusive domain of the U.S. Although listing all of the inventions that have advanced the science of computers would exceed the limits of this brief history, some of the more important developments have been described below.

Some inventions have been so momentous, advancing the state of the art by great leaps, that they now serve to differentiate between different generations of computers. The first generation of computers--the Mark I and EDVAC, for instance--was characterized by vacuum tube technology. During this period, numerous developments were made, but probably the most influential was the invention of ferrite-core memories. Core memories, generally acknowledged as the work of Jay Forrester at MIT, not only eventually replaced the CRT and other memory technologies because they were cheaper and more reliable, but encouraged another important development: higher-order languages.⁵⁷

Until Higher-order languages (HOLs) were invented, programming was done by only those scientists or technicians who had intimate knowledge of the design of the computer that was to be programmed. Programming had improved since the time when it had been necessary to rewire ENIAC, but only to the point that instructions to the machine consisted of a line of zeroes and ones, or at the best, a mixture of letters and numbers that made very little sense.⁵⁸ Finally, with the invention of ferrite-core memories, and the corresponding production of cheaper memory, it was possible to store in computers a program that could translate

programs written in a HOL into the machine's language of zeroes and ones: a step that would have been too expensive with existing technology.⁵⁹

In 1947, John Bardeen, Walter Brattain, and William Shockley, three physicists working for Bell Labs, invented the transistor.⁶⁰ The transistor had many advantages over vacuum tubes: it was 200 times smaller than even the smallest vacuum tube; since it was solid, it was not as fragile; it was much more reliable; it required less energy; and, finally, it dissipated far less heat.⁶¹ With so many positive aspects, the transistor was soon incorporated into computers, launching the second generation of computers in 1959.⁶²

The third generation of computers was launched when Jack Kilby, working for Texas Instruments, created the integrated circuit (IC) in 1958.⁶³ The IC, just as the transistor had done before it, shrank electronic components by orders of magnitude. Although initially quite expensive, ICs finally became cheaper and more reliable than transistors, resulting in the fact that they were common by 1965.⁶⁴ Eventually electronic circuits could be miniaturized to the degree that a new generation was declared to have begun: the present generation of very large-scale integration (VLSI).

As stated previously, the United States has been responsible for most of the developments, until recently, that have been made in computer history. Of course, other countries built computers, too. By 1953, in addition to machines constructed in Britain, computers had been completed or begun in Canada, Australia,

Norway, Germany, Switzerland, France, Holland, Belgium, Sweden, and Japan;⁶⁵ but the U.S. had opened a wide lead.

During the fourth generation, however, in 1976, Japan initiated the VLSI Technology Research Association which successfully supervised an effort to develop VLSI circuits for Japanese computers to compete directly with the pinnacle of American computer superiority--IBM.⁶⁶ In fact, the Japanese strategy worked so well, that Japan is now "the only country in the world where the market share of IBM is less than 50%."⁶⁷

Having essentially eliminated the United States' computer technology lead, the Japanese now look to establish a lead of their own by launching the fifth generation. Until now, all computers have followed a basic design known as the von Neumann machine, named for its originator, John von Neumann. The Japanese, however, plan to depart from its standards--a central processor, a memory, an arithmetic unit, and input/output devices--substituting their own devices, to create an entirely new breed of machines that will, for the first time, be able to process knowledge intelligently.⁶⁸ With this new technology, the Japanese expect to increase the speed of processing from its present ten or one hundred thousand logical inferences per second to 100 million to a billion!⁶⁹

The computer may have taken a long while to develop, with its origins in the abacus of thousands of years ago, but now that it has finally made its debut, progress has been amazing. Computational speed, power, and applications are continually growing by ever larger leaps and bounds.

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